The Wood Strengthening and Decorative Automated Production Line ZY-06L-Type Manipulator Motion Analysis and Simulation

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Abstract: ZY-06L-type manipulator is the important components of Wood Surface layer Strengthening and Decorative Automated Production Line, designed for a variety of sheet metal or semi-finished components handling, distribution and laying work in the workshop. Through the establishment of the manipulator kinematics equations, combined the position coordinates of the manipulator and object in the actual work environment, and solving this equation to get the relationship between the manipulator end-effectors position and posture with the joint variables. The use of engineering software UG NX8.0 for modeling and simulation of the manipulator, and analysis the reasonableness of structural and workflow design. Provide the basis and reference to the manipulator structure optimization and control systems developments. Copyright © 2014 IFSA Publishing, S. L.

Keywords: Timber processing, Manipulator, Kinematics equations, Simulation analysis.

1. Introduction

Manipulator (Industrial robots), the important manifestation of advanced manufacturing technology of modern industry, play an important role in many industrial categories. Industrial robots and flexible manufacturing systems combined, changing the basic design of the manufacturing system, greatly improved the production automation, efficiency and product quality [1].

ZY-06L-type manipulator is the important components of Wood Surface layer Strengthening and Decorative Automated Production Line. Undertakes the role of sheet metal or semi-finished components handling, distribution and laying in the system, and plays an important role that improve production line efficiency and product quality.

2. Manipulator Structure

Manipulator composed by the drive original, control module, and the main structural parts of base, rotating base, lower arm, intermediate arm, upper arm, swing arm, the end effectors, etc. as shown in Fig. 1.

This manipulator designed for a variety of sheet metal or semi-finished components handling, distribution and laying work in the workshop. Due to the material needs to move back and forth in the workshop, and the space pose complex. So for manipulator the carrying capacity, DOF, scope of work and efficiency of requirements higher, for motion accuracy requires relatively low. Therefore, manipulator rotating base, lower arm, intermediate arm, upper arm, swing arm, and the end effectors are
hydraulic drive, and control joints variable error in the range of design requirements by angle sensor feedback.

![ZY-06L manipulator diagram](image)

Fig. 1. ZY-06L manipulator.

### 3. Kinematics Equations

In the Space opened-chain mechanism, various structural components connected by joints, one end of the opened-chain mechanism mounted on the base and the other end connected to the end effectors.

Each joint by the motor, hydraulic cylinders, hydraulic motors to drive, the relative movement mechanism causes the joint movement, thereby determining the end effectors position and orientation in the 3D coordinates.

The equations kinematics of institution building and solving, fundamental purpose is to establish end-effectors position and orientation relationship with the joint variables. Further studies on the mechanism and optimization, provide a theoretical basis for mechanism design, and provide a basis and parameter for the control systematic study [2-4].

Each components of the mechanism as a rigid body, then the components movement in space becomes rigid body motion.

Space arbitrary motion of a rigid body can be regarded as the synthesis of two sub-movement, around a rotation axis and a translation along an axis [1]. Therefore, the main structural member of the manipulator as a rigid body, establish kinematical diagram shown in Fig 2.

The coordinate system transformation relationship in the kinematical diagram as follows.

![Manipulator kinematical diagram](image)

Fig. 2. Manipulator kinematical diagram.
Table 1. Manipulator rod D-H parameter table.

<table>
<thead>
<tr>
<th>No. rod</th>
<th>Joint variables</th>
<th>Rod twist angle</th>
<th>Rod length</th>
<th>No. rod</th>
<th>Joint variables</th>
<th>Rod twist angle</th>
<th>Rod length</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$\theta_1$</td>
<td>0</td>
<td>L_1</td>
<td>4</td>
<td>$\theta_4$</td>
<td>0</td>
<td>L_4</td>
</tr>
<tr>
<td>2</td>
<td>$\theta_2$</td>
<td>0</td>
<td>L_2</td>
<td>5</td>
<td>$\theta_5$</td>
<td>0</td>
<td>L_5</td>
</tr>
<tr>
<td>3</td>
<td>$\theta_3$</td>
<td>0</td>
<td>L_3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[
^0T = rot(z_0, \theta)_{trans(0,0,L_r)} \\
= \begin{bmatrix}
\cos \theta & -\sin \theta & 0 & 0 \\
\sin \theta & \cos \theta & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

\[
^1T = rot(x_1, \theta)_{trans(0,0,L_r)} \\
= \begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & \cos \theta_1 & -\sin \theta_1 & 0 \\
0 & \sin \theta_1 & \cos \theta_1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

\[
^2T = rot(y_2, \theta)_{trans(0,0,L_r)} \\
= \begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & \cos \theta_2 & -\sin \theta_2 & 0 \\
0 & \sin \theta_2 & \cos \theta_2 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

\[
^3T = rot(z_3, \theta)_{trans(0,0,L_r)} \\
= \begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & \cos \theta_3 & -\sin \theta_3 & 0 \\
0 & \sin \theta_3 & \cos \theta_3 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

\[
^4T = \prod_{i=1}^{3} ^iT 
\]

where

\[
A_1 = \begin{bmatrix}
\cos \theta_1 & -\sin \theta_1 & 0 & 0 \\
\sin \theta_1 & \cos \theta_1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

\[
A_2 = \begin{bmatrix}
\cos \theta_2 & -\sin \theta_2 & 0 & 0 \\
\sin \theta_2 & \cos \theta_2 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

\[
A_3 = \begin{bmatrix}
\cos \theta_3 & -\sin \theta_3 & 0 & 0 \\
\sin \theta_3 & \cos \theta_3 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

\[
C_1 = \begin{bmatrix}
\cos \theta_1 & \sin \theta_1 & 0 & 0 \\
-\sin \theta_1 & \cos \theta_1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

\[
D_1 = L_1 \begin{bmatrix}
\cos \theta_1 & \sin \theta_1 & 0 & 0 \\
-\sin \theta_1 & \cos \theta_1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\]
4. Motion Analysis and Simulation

UG NX8.0 motion simulation analysis module UG / Motion providers sport / dynamic simulation analysis capabilities. Motion simulation exercise can interfere with the analysis, motion trajectory tracking, and analysis of parts of displacement, velocity, acceleration, force, torque reaction and so on. The results can guide the design optimization and tuning, design changes can be reflected in the assembly of the model.

In the motion simulation, set up 55 pairs of ordinary deputy campaign and 3 pairs of special deputy campaign, the specific types and quantities are as follows [6-8].

Fixed deputy campaign. 1 pair, connected to the base support and geodetic coordinate system.

Sliding deputy campaign. 7 pairs, connected to the 7 cylinders and piston.

Cylinder deputy campaign. 1 pair, connected to the manipulator swing arm and end effectors.

Rotational deputy campaign. 46 pairs, connect all remaining connecting rod.

Gear deputy campaign. 3 pairs, connection gear.

4.1. Motion Scheme

In order to obtain the manipulator motion parameters, according the actually situation to simulation the manipulator complete movement, test the reasonableness of the manipulator movement and motion states any time.

Referring to the actual position of the manipulator in the production line, obtained the coordinates of manipulator initial position, object initial position and the target location, as shown in Table 2.

<table>
<thead>
<tr>
<th>Location</th>
<th>Coordinate values(mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manipulator initial position</td>
<td>X₀Y₀Z₀ (1500, 0, 3200)</td>
</tr>
<tr>
<td>Object initial position</td>
<td>X₀Y₀Z₀ (-2100, 600, 4050)</td>
</tr>
<tr>
<td>Object target location</td>
<td>X₀Y₀Z₀ (3210, 0, 4100)</td>
</tr>
</tbody>
</table>

Solving motion equations according coordinate parameters of Table 2. get each joint variable values that manipulator end effectors in the manipulator initial position, object initial position and object target location, as shown in Table 2. According to the parameters in Table 3, and reference the shape of manipulator carrying objects, arrangement manipulator motion program, as shown in Table 4.

Tab 3. The joint variables of manipulator in three kinds of position and orientation.

<table>
<thead>
<tr>
<th>Joint variable</th>
<th>Manipulator initial position</th>
<th>Object initial position</th>
<th>Object target location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q₁</td>
<td>0°</td>
<td>166°</td>
<td>-14°</td>
</tr>
<tr>
<td>Q₂</td>
<td>45°</td>
<td>34°</td>
<td>50°</td>
</tr>
<tr>
<td>Q₃</td>
<td>160°</td>
<td>68°</td>
<td>63°</td>
</tr>
<tr>
<td>Q₄</td>
<td>-160°</td>
<td>-89°</td>
<td>-62°</td>
</tr>
<tr>
<td>Q₅</td>
<td>0°</td>
<td>150°</td>
<td>0°</td>
</tr>
</tbody>
</table>

4.2. Motion Drive

The number of manipulator DOF is 6, need 7 motion driving. According to motion scheme, the use of STEP function to add the drive, as shown in Table 5.

4.3. Simulation and Results

Set motion simulation time is 185S, step number 18500, the solver of ADAMS inspection and solver the simulation model. If the simulation model has errors, the error message dialog box pops up, and debug the model according to the message. If the simulation model is correct, then the simulation results output [9, 10]. Simulation according to the motion scheme of Table 4, the action of manipulator shown in Fig 3, the motion parameters of manipulator end effectors as shown in Fig. 4, Fig. 5 and Fig. 6.
### Table 4. Motion scheme.

<table>
<thead>
<tr>
<th>Time</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 s~9 s</td>
<td>Base counter-clockwise 166 °</td>
</tr>
<tr>
<td>9 s~11 s</td>
<td>All stationary</td>
</tr>
<tr>
<td>11 s~20 s</td>
<td>Lower arm swings clockwise 11 °</td>
</tr>
<tr>
<td>20 s~35 s</td>
<td>Upper arm swings counter-clockwise 71°</td>
</tr>
<tr>
<td>25 s~40 s</td>
<td>Intermediate arm swings clockwise 92°</td>
</tr>
<tr>
<td>40 s~50 s</td>
<td>End effectors turn 90°</td>
</tr>
<tr>
<td>50 s~55 s</td>
<td>End effectors fingers open</td>
</tr>
<tr>
<td>55 s~65 s</td>
<td>Swing arm turn left 150°</td>
</tr>
<tr>
<td>65 s~70 s</td>
<td>Fingers together (pinching)</td>
</tr>
<tr>
<td>70 s~80 s</td>
<td>Swing arm return (-150°)</td>
</tr>
<tr>
<td>80 s~90 s</td>
<td>Upper and intermediate arm return; Lower arm swings counter-clockwise 45°</td>
</tr>
<tr>
<td>90~100 s</td>
<td>Rotating base clockwise rotation 180°</td>
</tr>
<tr>
<td>100 s~115 s</td>
<td>Intermediate arm swings clockwise 97°</td>
</tr>
<tr>
<td>110 s~120 s</td>
<td>Upper arm swings counter-clockwise 63°</td>
</tr>
<tr>
<td>120 s~123 s</td>
<td>The still (sensor feedback correction time)</td>
</tr>
<tr>
<td>123 s~135 s</td>
<td>End effectors turn 90°</td>
</tr>
<tr>
<td>135 s~138 s</td>
<td>The still (corrected again)</td>
</tr>
<tr>
<td>138 s~150 s</td>
<td>Upper arm swings counter-clockwise 35°</td>
</tr>
<tr>
<td>143 s~153 s</td>
<td>Lower arm swings clockwise 29°</td>
</tr>
<tr>
<td>153 s~158 s</td>
<td>End effectors fingers open (Down objects)</td>
</tr>
<tr>
<td>158 s~163 s</td>
<td>The still (detecting objects final position)</td>
</tr>
<tr>
<td>163 s~173 s</td>
<td>Lower arm return</td>
</tr>
<tr>
<td>170 s~180 s</td>
<td>Upper arm return</td>
</tr>
<tr>
<td>175 s~185 s</td>
<td>Intermediate arm return</td>
</tr>
</tbody>
</table>

### Table 5. Motion drive.

<table>
<thead>
<tr>
<th>Motion</th>
<th>Motion Drive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base rotation</td>
<td>STEP(TIME,0,0,9,2.9)+STEP(TIME,90,0,100,-3.14)</td>
</tr>
<tr>
<td>Lower arm swings</td>
<td>STEP(TIME,11,0,20,-0.2)+STEP(TIME,80,0,90,0.7)+STEP(TIME,143,0,153,-0.5)+STEP(TIME,163,0,173,0.3)</td>
</tr>
<tr>
<td>Intermediate arm swings</td>
<td>STEP(TIME,25,0,40,1.6)+STEP(TIME,80,0,90,-1.2)+STEP(TIME,100,0,120,1.7)+STEP(TIME,175,0,185,-1.7)</td>
</tr>
<tr>
<td>Upper arm swings</td>
<td>STEP(TIME,20,0,35,1.25)+STEP(TIME,80,0,90,-1.3)+STEP(TIME,105,0,120,1.1)+STEP(TIME,138,0,150,0.6)</td>
</tr>
<tr>
<td>Swing arm swings</td>
<td>STEP(TIME,55,0,65,2.6)+STEP(TIME,70,0,80,-2.6)</td>
</tr>
<tr>
<td>End effectors swings</td>
<td>STEP(TIME,40,0,50,3.2)+STEP(TIME,123,0,135,3.1)</td>
</tr>
<tr>
<td>End effectors task</td>
<td>STEP(TIME,50,0,55,26)+STEP(TIME,65,0,70,-100)+STEP(TIME,153,0,158,100)</td>
</tr>
</tbody>
</table>

![Fig. 3. Motion simulation action Screenshots.](image-url)
Fig. 4. The end effectors displacement, velocity, acceleration curve (X-axis component).

Fig. 5. The end effectors displacement, velocity, acceleration curve (Y-axis component).

Fig. 6. The end effectors displacement, velocity, acceleration curve (Z-axis component).
7. Conclusions

ZY-06L-type manipulator developed. The purpose is to improve the production efficiency, degree of automation, product quality of wood surface layer strengthening and Decorative Automated Production Line, and improve enterprise efficiency.

Through the establishment of the manipulator motion equations, get the relationship between the manipulator end-effectors position and posture with the joint variables. Analysis manipulator working process, substituting the parameters and solving the motion equations, and get the manipulator joint variables of three kinds of conditions. According manipulator workflow, the simulation results are as follows. The displacement of manipulator end-effectors achieves the design requirements. When the end-effectors in the initial position (0S), the object initial position (70S) and object target location (160S), the position and attitude is consistent with the expected value, and the speed and load changes are within the scope of the requirements. The creating and solving of manipulator motion equations is correct, action reasonable, the manipulator design is feasible.

References